

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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1. AGENCY USE ONLY (LEAVE BLANK)		2. REPORT DATE 10 September 1998		3. REPORT TYPE AND DATES COVERED Professional Paper
4. TITLE AND SUBTITLE The Use of Ejection Simulation in Mishap Investigations			5. FUNDING NUMBERS	
6. AUTHOR(S) Jeffrey P. Nichols				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Air Systems Command 47123 Buse Road, Unit IPT Patuxent River, Maryland 20670-1547			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) Modeling and simulation of ejection events can be a valuable tool in the investigations of aircraft mishaps. Engineers at NAVAIRSYSCOM Patuxent River, Maryland, frequently utilize 6 degree-of-freedom modeling and simulation to aid in mishap investigations. Simulations are used to reenact the mishap and evaluate many aspects of the event. Initial conditions and impact conditions can be examined; the time when the envelope for safe ejection was exceeded can be determined; possible system malfunctions can be investigated, and possible improvements to the seat systems can be evaluated using the actual mishap conditions.				
14. SUBJECT TERMS Ejection simulation Mishap				15. NUMBER OF PAGES 8
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

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THE USE OF EJECTION SIMULATION IN MISHAP INVESTIGATIONS

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ABSTRACT

Modeling and simulation of ejection events can be a valuable tool in the investigations of aircraft mishaps. Engineers at the Naval Air System Command, Patuxent River, MD frequently utilize 6 degree of freedom modeling and simulation to aid in mishap investigations. Simulations are used to reenact the mishap and evaluate many aspects of the event. Initial conditions and impact conditions can be examined; the time when the envelope for safe ejection was exceeded can be determined; possible system malfunctions can be investigated, and possible improvements to the seat systems can be evaluated using the actual mishap conditions.

INTRODUCTION

When mishaps occur involving U. S. Navy aircraft, investigations are conducted to determine the cause of the mishaps and determine actions that could prevent similar mishaps in the future. Investigators for the Aircraft Mishap Board (AMB) and/or the Judge Advocate General (JAG) Office frequently call upon engineers in the In-Flight Escape Systems branch at the Naval Air Systems Command, Aircraft Division,

Patuxent River (NAVAIR) to conduct ejection simulations to aid in the investigation.

SIMULATION DESCRIPTION

Engineers at NAWCADPAX utilize the Navy's ACCESS V6 modeling and simulation software to conduct mishap analysis. This software models all phases of an ejection and simulates the dynamics on an ejection in 6 degrees of freedom (6 DOF). Significant areas of input to the model include: ejection conditions, aircrew inertial properties, forces generated by subsystems, subsystem inertial properties and interfaces, aerodynamic forces and moments, and system mode of operation. Figure 1 shows a graphic representation of the modeling process.

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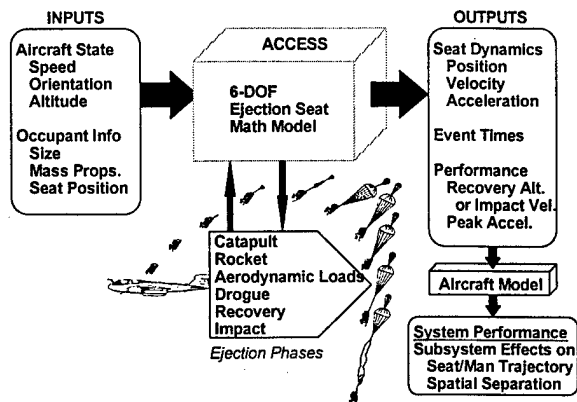


Figure 1: ACCESS Ejection Seat Modeling

INVESTIGATION REQUESTS

When investigators request simulations to be conducted there are often very specific questions which need to be answered. Some of the more frequently asked questions include: did the escape system perform as it was designed to, at what velocity did the aircrew impact the ground/water, at what stage in the ejection sequence did the aircrew impact the ground/water, did the aircrew impact aircraft structure, how much earlier did the aircrew need to pull the handle to survive the mishap, what could have caused the specific injuries observed, what were the initial conditions at ejection, where did the aircrew land, and what could we do to the escape system to extend the envelope to include the mishap conditions..

INVESTIGATION TECHNIQUES

To conduct simulation analysis of a mishap the ejection event must first be modeled. The inertial properties of the aircrew involved are incorporated with a preexisting model of the escape system used. Information provided by the requesting

agency is used to approximate the initial conditions to be used in the simulations. These include, altitude, attitude, linear and angular velocity and acceleration, aircraft trajectory, wind speed and direction, temperature and impact surface. Unfortunately, there is often limited information about the initial conditions. In these cases a significant amount of work may be required simply to approximate the initial conditions.

Once the initial conditions have been determined, the series of simulations to be conducted are begun. This is typically an iterative process. Simulations are run and the results of the simulations are compared to the known outcome of the mishap. If the results of the simulations differ from the mishap, the simulation parameters are varied and the simulations are rerun. In some cases only a few simulations are required in other cases thousands of simulations are needed to evaluate what might have happened in the mishap.

CASE STUDIES

The following are a few examples of mishap investigation simulations efforts conducted. All of the cases included are actual mishaps. Details regarding date and location have been intentionally omitted.

T-2 FATALITY

A T-2 mishap occurred in which the pilot was flying the two seat aircraft from the forward crewstation. The aft seat was unoccupied. The aircraft got into an unrecoverable situation and the pilot initiated an ejection.

An ejection initiated from the forward seat of a T-2 results in a command ejection. In a command ejection the canopy is jettisoned immediately, the aft seat is ejected at ~0.3 seconds after canopy jettison, and the fwd seat is ejected ~0.6 seconds after the aft seat. In this mishap a typical command ejection occurred. The pilot was observed ejecting from the aircraft at ~25 ft above ground level (AGL). Figure 2 shows and illustration of a T-2 ejection.

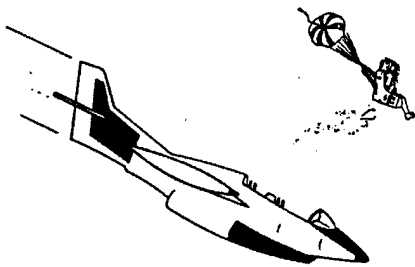


Figure 2: T-2 Ejection

Simulations were conducted to reenact the mishap and determine the ejection trajectories, impact velocities and minimum safe altitude for recovery. A number of simulations were run to determine when the ejection was initiated. The initiation altitude which would result in the pilot leaving the aircraft at ~25 ft AGL was found. Figure 3 shows the trajectories of the aircraft and the seats which were calculated in the simulations. The simulations indicated that the ejection was initiated at less than 250 ft AGL and the pilot impacted the ground prior to seat/man separation with a velocity of ~520 ft/sec. The ejection was determined to be out of envelope.

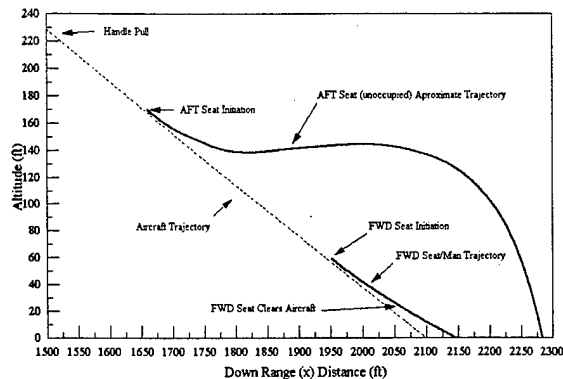


Figure 3: T-2 Mishap Trajectories

Once the mishap had been reenacted, additional simulations were conducted to estimate when the aircraft left its envelope for safe recovery. It was determined that the pilot initiated ejection approximately one second after the aircraft had passed below its minimum safe altitude for ejection. Though it would not have prevented the fatality in this mishap, it was noted in this investigation that had the aircraft had the capability of ejecting the pilot alone without the command ejection delay, the envelope for safe recovery would have been expanded.

FOREIGN A-4 FATALITY

Simulation analysis is sometimes performed to aid foreign countries in investigations of mishaps in aircraft purchased from the U.S.A.. This work can be challenging as it often involves escape systems that are many decades old for which there is limited performance data available. Often the primary question asked is: did the system work as it was supposed to.

In this mishap an ejection occurred with relatively benign initial conditions. As stated, however, the aircrew was killed. The mishaps

was simulated and the trajectory of the seat/aircrew was calculated. Figure 4 shows the simulated ejection trajectory in this mishap. As can be seen in this Figure, the simulations indicated that the ejection should have been successful. The fatality was likely the result of improper maintenance or operation of the escape system.

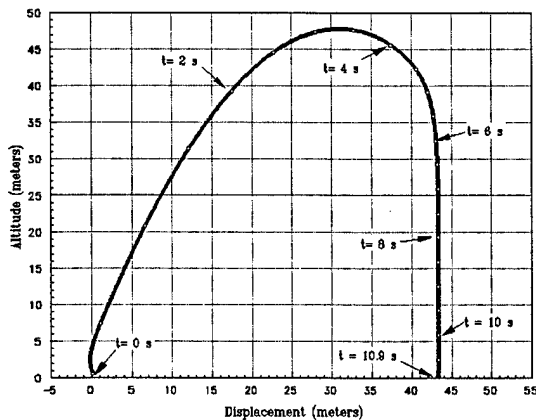


Figure 4: A-4 Ejection Trajectory

A-6 PISONER OF WAR (POW)

On some occasions simulation efforts are conducted to locate the landing site of an aircrew. In this case an A-6 ejection occurred behind enemy lines and the pilot was believed to have been taken as a POW. The impact site of the downed aircraft was known as were the approximate altitude and airspeed at ejection. The investigators wished to know where the aircrew touched down relative to the aircraft impact site. Simulations were conducted to determine possible landing sites of the aircrew. Because this ejection occurred at ~2000 ft AGL, the effect of wind on the aircrew trajectories was an important consideration. The simulation results shown in Figure 5.

The distance and direction from the aircraft impact site to the likely aircrew landing site were provided to the investigators and were used to aid in search and rescue operations.

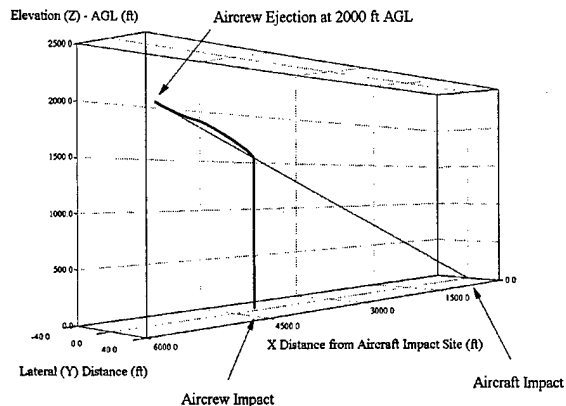


Figure 5: A-6 Ejection Trajectory

AV-8 FATLITY

An AV-8 ejection occurred which resulted in a fatality. In this mishap the ejection was not witnessed and the actual time which the ejection occurred was not known. To determine the cause of the fatality, it was necessary to determine the conditions at which the ejection occurred.

A significant amount of work was involved in estimating the ejection conditions. First the seat was examined and it was found that the seat functioned in mode 1. Next the Data Storage Unit (DSU) data from the aircraft was examined and the times at which the seat would function in mode 1 were identified (shown in Figure 6). The radar tapes of the mishap were then reviewed and the radio transmissions were synched with the radar tapes. The radar tapes were then synched to the DSU data allowing the time of the last

voice transmission to be identified in the DSU data. This identified the point in the flight path where the pilot announced the intention to eject. Next the testimony of the wingman was reviewed. The wingman observed the aircraft impact, so a near ground ejection was ruled out. All of this information allowed the possible point of ejection to be narrowed down to two areas of the flight path. To further narrow down the ejection time, simulations were conducted. Using the flight conditions from the DSU data, the mishap was simulated at various points along the flight path and the impact location of the seat, pilot, and aircraft were calculated. By comparing the simulated impact locations to the actual impact locations in the mishap, one of the areas of the flight path was eliminated and the possible time of ejection was narrowed down to a 15 second window. Figure 6 shows the transitions of the mishap aircraft through the modes of operation of the seat and the determined window of ejection.

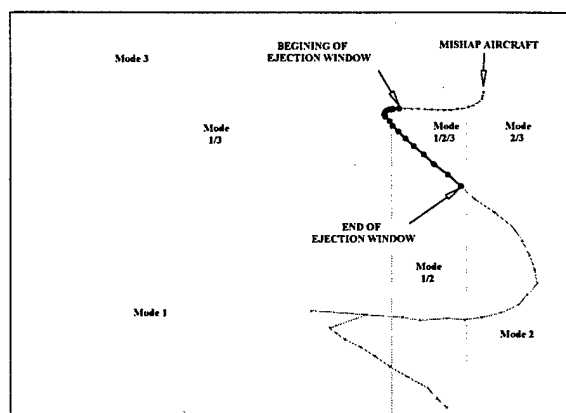


Figure 6: Mishap Ejection Window

Once the ejection conditions were bounded by determining the approximate time that the ejection occurred simulations, were

conducted to determine the causes for the injuries which occurred in the mishap. The simulations did indicate that the ejection loads in this mishap could result in injuries such as those seen. Possible causal factors were identified and possible seat improvements were recommended.

F-14 SINGLE FATALITY

A F-14 mishap occurred in which the aft seat aircrew, the Radar Intercept Officer (RIO), was recovered, but the fwd seat aircrew, the pilot, was killed. The physical evidence recovered in this mishap indicated that the fatality was a result of pilot's ejection seat impacting the tail of the aircraft. Figure 7 shows and illustration of this mishap.

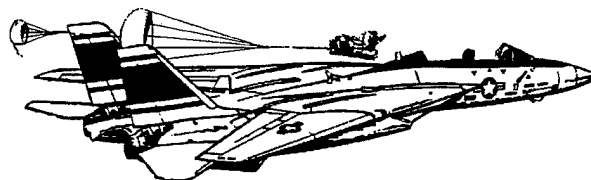


Figure 7: F-14 Mishap

A reviews of test data and previous mishaps were conducted to identify any possible tail clearance problems which may have been identified in the past. Tests conducted around the airspeed of the mishap demonstrated excellent tail clearance. Figure 8 shows the tail clearance seen in sled testing. One previous mishap was found in which an ejection seat impacted the tail. In this previous mishap, the aircraft was essentially in an inverted flat spin and the aircraft overtook the ejection seat after it had left the cockpit. The ejection conditions of the mishap under investigation, however, were not similar to the previous mishap.

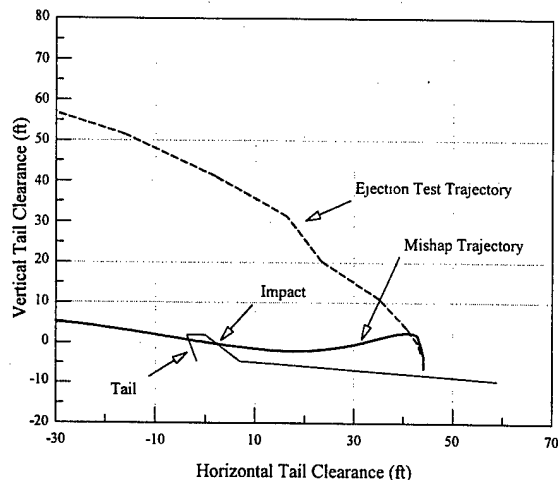


Figure 8: Test & Mishap Tail Clearance

To attempt to determine what could have resulted in impact with the tail, a series of simulations were begun. Using the basic initial conditions given, variations in airspeed, pitch, roll, pitch rate, roll rate, acceleration, angle of attack, center of gravity, and center of pressure were modeled.

In the initial simulations conducted, the results indicated that the pilot should have passed well clear of the tail.

Additional simulations were run looking at wider variations in the ejection parameters as well as component malfunctions such as underseat rocket motor failure and catapult cartridge failure. Over 2800 simulations were run before it was felt that all reasonable causes for tail impact had been explored. In those 2800 simulations, 3 cases were found which resulted in tail impact. Two of the cases involved extreme initial conditions in which, as in the flat spin mishap described above, the tail overtook the ejection seat. The third case involved a catapult stall. The

catapult stall case, though unlikely, was felt to be more probable than the extreme initial condition cases.

If a catapult stall occurs, the seat can have a low vertical velocity when it leaves the cockpit of the aircraft. Additionally, if a catapult stall occurs, the drogue can be deployed prior to the seat leaving the cockpit. A low vertical velocity coupled with the down stream pull of the drogue can result in the seat traveling toward and impacting the tail. Figure 8 above shows the trajectory of the seat with respect to the tail in the catapult stall simulation. Figure 9 below shows the trajectories of the tail and seat in the same simulation.

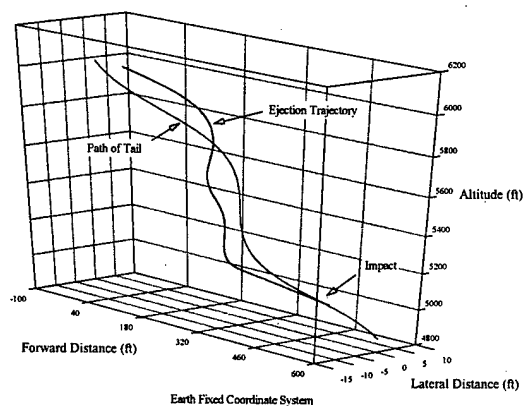


Figure 9: Catapult Stall Mishap Trajectory

A-6 DUAL FATALITY

An A-6 mishap occurred which resulted in the death of both the pilot and bombardier/navigator (B/N) with injuries to the B/N's body notably more severe. The aircraft was rolled approximately 90 deg left at the time of ejection. In the A-6 a command ejection can be initiated by either aircrew. The aircrew initiating the ejection will eject

first. It is possible in this aircraft for both aircrew to initiate ejection at the same time and eject simultaneously. It was not known who initiated ejection in this mishap.

Simulations were conducted to determine the order of ejection and the impact velocities. The injuries to the B/N indicated that the B/N impacted with a higher velocity and therefore was the last to leave the aircraft. The simulations did indicate that the ejection was pilot initiated and that the pilot left the aircraft before the B/N. The impact velocity of the pilot calculated by the simulations was ~75 ft/sec, the impact velocity of the B/N was over 150 ft/sec. The ejection was determined to be out of envelope.

While conducting the simulations for this mishap it was noted that in the simultaneous ejection simulations, with both of the aircrew leaving the aircraft at the same time, the B/N had a lower impact velocity than the pilot. This was found to be a result of the seat divergence. In this aircraft, the pilot seat diverges left and the B/N seat diverges right. With the 90 deg. left roll of the aircraft in this mishap, the B/N right divergence partially righted the B/N seat while the pilot left divergence partially turned the pilot seat toward the ground. Figure 10 shows the velocities and trajectories that would result in a simultaneous ejection in the mishap conditions. It can be seen in this figure that the right diverging seat has a more upward trajectory and a significantly lower impact velocity. Unfortunately the effect of the B/N divergence was not enough to recover the aircrew in the mishap.

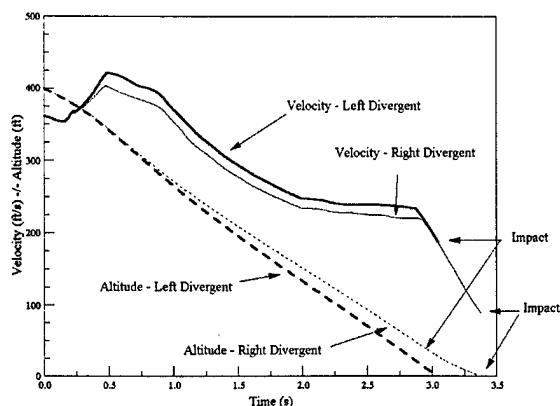


Figure 10: A-6 Ejection Velocities & Trajectories with 90 deg Roll Left

This righting effect of divergence raised the question of possibly implementing a seat design which could control trajectory. The USN and USAF have demonstrated an ejection seat which utilizes controllable propulsion to allow trajectory control and high speed stability. Simulations of this mishap were conducted using this seat: the 4th Generation Escape System (4th Gen). These simulation allowed the performance of the 4th Gen seat to be evaluated in actual mishap conditions and compared to current seat systems. Figure 11 shows a comparison of the trajectories and velocities of the mishap seat, a GRU-7, and the 4th Gen seat. With the 4th Gen seat, the aircrew reaches a safe impact velocity at over 300 ft AGL. With the GRU-7, the aircrew does not reach a safe impact velocity.

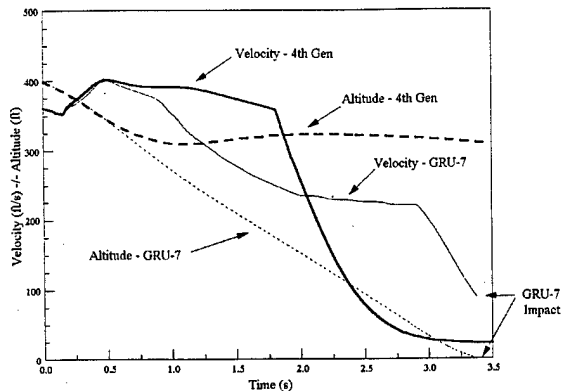


Figure 11: Velocity & Trajectory Comparison

To further evaluate the benefit of seat improvements the required altitude for safe recovery was calculated for the 4th Gen seat and the GRU-7 seat in this mishap. Figure 12 shows the results of these simulations. The impact velocity vs. altitude at ejection is shown in this Figure. The altitude at which the impact velocity will be less than 30 ft/sec is judged to be the altitude for safe recovery. As can be seen in the figure the GRU-7 seat requires over 400 ft of altitude for safe recovery in this mishap while the 4th Gen seat requires less than 100 ft.

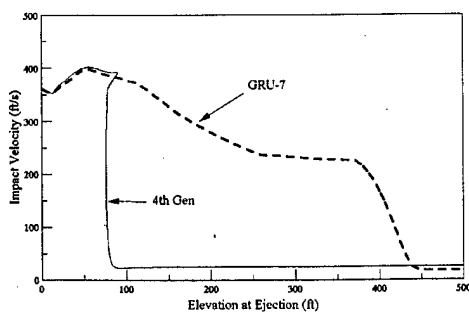


Figure 12: Altitude for Safe Recovery Comparison.

CONCLUSIONS

Ejection simulation can be a valuable tool in mishap investigation. When used in conjunction with the mishap evidence and other investigation tools, simulations can be used to answer questions regarding the mishap from beginning to end. They can be used to evaluate possible causes of the mishap as well as possible solutions to future mishaps.

Biography: Mr. Nichols holds a B.S. degree in Mechanical Engineering from the Pennsylvania State University and has completed additional course work in Aerospace Engineering also at the Pennsylvania State University. He has worked in the In-Flight Escape Systems Branch at the Naval Air Systems Command since 1990. He has been involved in escape systems design, development, analysis, testing, and in-service engineering support. Mr. Nichols has also conducted extensive modeling and simulation efforts in support of mishap investigations.